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(54) Title: MODIFIED PICTET-SPENGLER REACTION AND PRODUCTS PREPARED THEREFROM

(57) Abstract: A method of introducing a second stereogenic center into a tetrahydro-B-carboline have two stereogenic centers using a modified Pictet-Spengler reaction is disclosed. The method provides a desired cis- or trans-isomer in high yield and purity, and in short processes times.

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**MODIFIED PICTET-SPENGLER REACTION
AND PRODUCTS PREPARED THEREFROM**

FIELD OF THE INVENTION

The present invention relates to a modified Pictet-Spengler reaction for introducing a second stereogenic center into a compound. More particularly, the present invention relates to a modified Pictet-Spengler reaction that provides a desired *cis*- or *trans*-diastereomer of a polycyclic compound having two stereogenic centers, in high yield and high purity.

BACKGROUND OF THE INVENTION

Compounds that exhibit biological activity typically contain at least one asymmetric carbon atom, i.e., at least one chiral center. A particular stereoisomer of such a compound usually exhibits excellent biological activity, whereas the other stereoisomers exhibit no or little biological activity. Accordingly, investigators strive to synthesize the biologically active stereoisomer, while minimizing or eliminating synthesis of the inactive or less active stereoisomer.

Stereochemical purity is important in the pharmaceutical field, where many of the most often prescribed drugs exhibit chirality. For example, the L-enantiomer of the β -adrenergic blocking agent, propranolol, is known to be 100 times more potent than its D-enantiomer. Additionally, optical purity is important in the pharmaceutical field because

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certain stereoisomers impart a deleterious effect, rather than an advantageous or inert effect. For example, it is believed that the D-enantiomer of thalidomide is a safe and effective sedative when prescribed for the control of morning sickness during pregnancy, whereas its corresponding L-enantiomer is believed to be a potent teratogen.

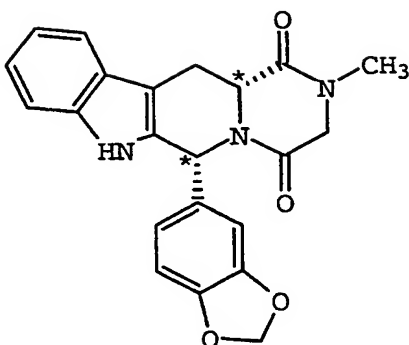
A stereoselective synthesis, therefore, permits the preparation of a more useful drug product. For example, the administered dose of a drug can be reduced because only the active stereoisomer is administered to an individual, as opposed to a mixture which contains a large amount of inactive stereoisomer. This reduced dose of active stereoisomer also reduces adverse side effects compared to a dose containing a mixture of stereoisomers. In addition, a stereoselective synthesis is more economical because a step of separating the desired stereoisomer from the undesired stereoisomer is simplified or eliminated, and raw material wastes and costs are decreased because reactants are not consumed in the synthesis of undesired stereoisomers.

Many biologically active compounds contain two asymmetric carbon atoms, i.e., two stereogenic centers, wherein each asymmetric carbon atom is a member of a ring system and each is bonded to a hydrogen atom and to a substituent different from a hydrogen atom. The nonhydrogen substituents of the asymmetric carbon atoms therefore can be in a cis or a trans configuration. A particularly difficult

problem encountered in the synthesis of such biologically active compounds is the high yield and high purity preparation of a particular stereoisomer, i.e., the desired diastereomer, wherein the
5 nonhydrogen substituents of the asymmetric carbon atoms are in the *cis* configuration, or the *trans* configuration, depending upon which diastereomer is the more biologically active.

For such compounds, it is necessary to
10 provide a synthetic pathway that provides each stereogenic center of correct stereochemistry, and thereby yield the desired diastereomer. The synthetic pathway also should provide a high yield of the desired diastereomer in as few steps as
15 possible, with a minimum of diastereomer separation and purification.

For example, U.S. Patent No. 5,859,006, incorporated herein by reference, discloses the synthesis of (6R,12aR)-2,3,6,7,12,12a-hexahydro-2-
20 methyl-6-(3,4-methylenedioxyphenyl)-pyrazino-[2',1':6,1]pyrido[3,4-b]indole-1,4-dione having a structure (I):



(I)

5

Compound (I) has two asymmetric carbon atoms,
each denoted by an asterisk, wherein the nonhy-
10 drogen substituents of the asymmetric carbon
atoms are in the *cis* configuration. Compound
(I) can be prepared by the two synthetic path-
ways disclosed in U.S. Patent No. 5,859,006.
Compound (I) is a potent and selective inhib-
15 itor of the phosphodiesterase enzyme PDE5, and
has various therapeutic uses, for example, the
treatment of male erectile dysfunction.

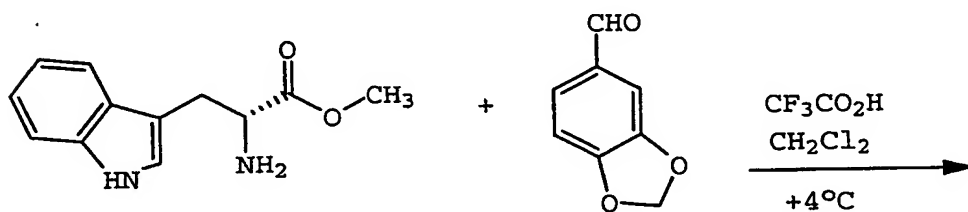
The first synthetic pathway (A), from D-
tryptophan, has few steps, but the yield of the de-
20 sired diastereomer (i.e., Compound II) is poor and
requires a separation step from the *trans*-stereo-
isomer (Compound IIa). Pathway (A) also utilizes
the highly corrosive trifluoroacetic acid (i.e., TFA
or CF₃CO₂H). The key step in pathway A is a classic
25 Pictet-Spengler reaction using D-tryptophan methyl
ester and piperonal to yield substituted tetrahydro-
β-carboline Compounds (II) and (IIa). The second

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pathway (B) provides a better yield of the desired Compound I, but requires numerous synthetic steps. In each synthetic pathway, the key intermediate in the synthesis of Compound (I) is Compound (II).

- 5 Compound (I) then is synthesized from Compound (II) in two straightforward synthetic steps.

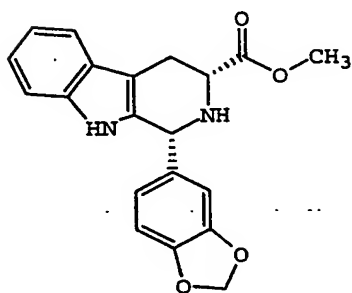
Pathway A



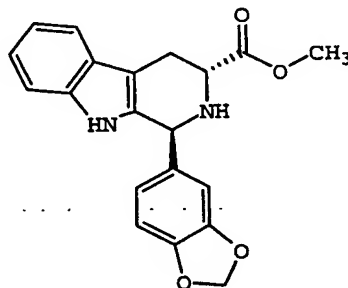
D-Tryptophan
methyl ester

Piperonal

10



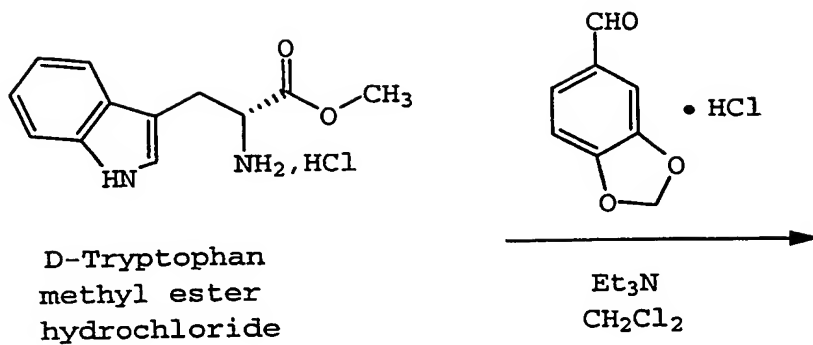
Compound (II)
(*cis*-isomer) (42% yield)
(desired)



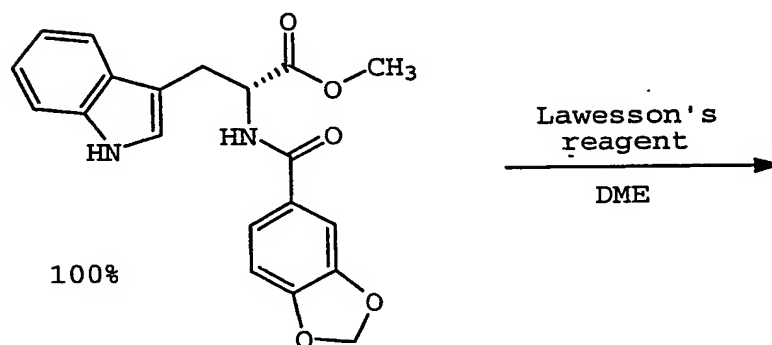
Compound (IIa)
(*trans*-isomer) (28% yield)
(undesired)

15

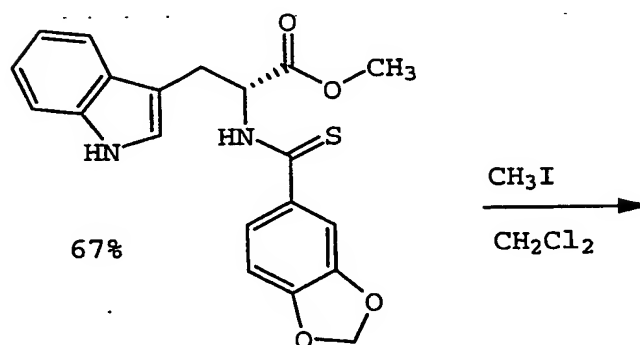
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Pathway B

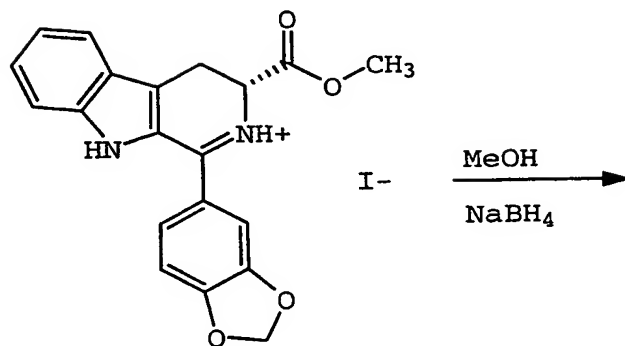
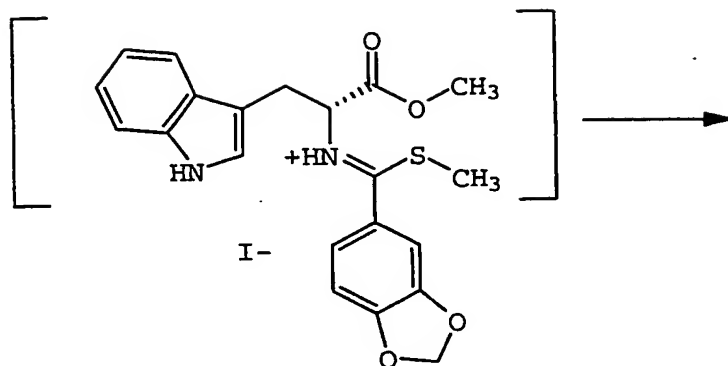
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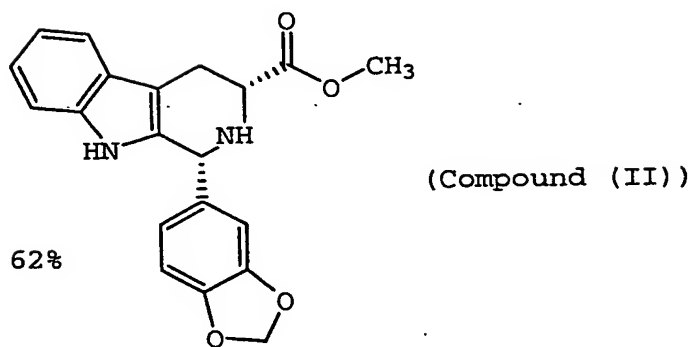
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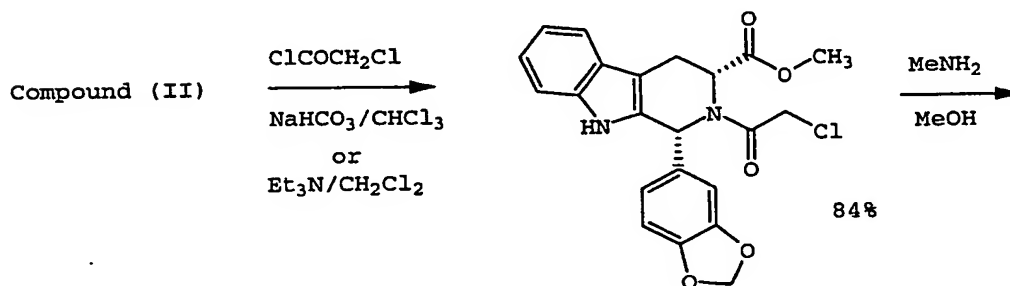
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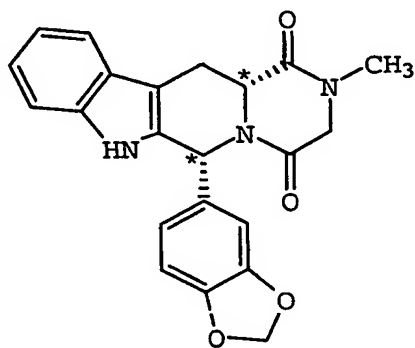
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Pathway from Compound (II) to Compound (I)

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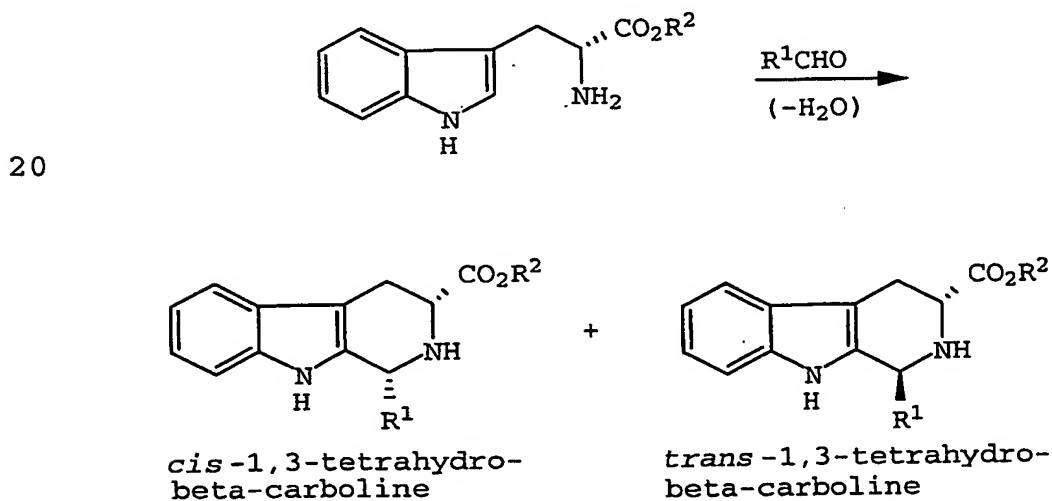
The overall yield of Compound (I) using synthetic pathway (A) or (B) is about 25% to about 30%.

Pathway (B) requires several synthetic steps, and, therefore, was considered inconvenient. A key step in the synthesis of Compound (I) is the preparation of Compound (II) in the shorter synthetic pathway (A). The preparation of Compound (II) in pathway (A) utilizes a Pictet-Spengler cyclization between D-tryptophan methyl ester and piperonal in dichloromethane (CH_2Cl_2) with two equivalents of trifluoroacetic acid at 4°C which

20

provides, after five days, a mixture of two diastereoisomers, i.e., the desired *cis*-isomer tetrahydro- β -carboline Compound (II) ((1*R*,3*R*)) and the undesired *trans*-isomer tetrahydro- β -carboline Compound (IIa) ((1*S*,3*R*)) in a ratio of about 60/40. From this mixture, the pure *cis*-isomer (i.e., Compound (II)) can be obtained by fractional crystallization in a 42% yield (ee>99% (chiral HPLC)).

The Pictet-Spengler reaction is a direct method of providing the tetrahydro- β -carboline ring system that is present in Compound (I). In general, the Pictet-Spengler reaction utilizes a tryptophan ester and an aldehyde to yield a mixture of the *cis*-1,3- and *trans*-1,3-tetrahydro- β -carbolines illustrated below. R^2 typically is C_{1-4} alkyl and R^1 can be aliphatic or aromatic, for example, see U.S. Patent Nos. 5,859,006 and 5,981,527, each incorporated herein by reference.



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It would be an important advance in the art to provide a modified Pictet-Spengler cyclization reaction that substantially improves the diastereoselectivity of the reaction. In particular, it would be an advance in the art to improve pathway A, which utilizes the Pictet-Spengler reaction between commercially available D-tryptophan methyl ester and piperonal, or other aliphatic or aromatic aldehyde, in a straightforward method to prepare enantiomerically pure Compound (II), or similar tetrahydro- β -carboline, and that overcomes the disadvantages of the classic Pictet-Spengler reaction, such as use of TFA, long reaction times, and difficult product separations.

15

SUMMARY OF THE INVENTION

The present invention is directed to a method of preparing a desired diastereomer, i.e., *cis* or *trans*, of a polycyclic compound having two asymmetric ring carbon atoms. More particularly, the present invention is directed to a method of preparing a desired diastereomer of a tetrahydro- β -carboline compound having two asymmetric carbon atoms utilizing a modified Pictet-Spengler reaction.

Prior investigators attempted to prepare a desired diastereomer of a polycyclic ring system containing two asymmetric ring carbon atoms by performing a Pictet-Spengler cyclization reaction. These attempts generally were limited in success because the reaction was performed in a corrosive medium, led to mixtures of diastereomers that ad-

versely affected reaction yield, and required several days to perform. The present method provides the desired diastereomer in good yield and short reaction times, and avoids the use of TFA.

5 More particularly, the present invention is directed to a method of preparing a desired diastereomer of a tetrahydro- β -carboline compound having two asymmetric carbons utilizing a modified Pictet-Spengler cyclization reaction wherein the
10 reaction is performed using a solvent in which only one of the diastereomers is soluble. In preferred embodiments, the desired diastereomer is insoluble in the solvent, and undesired diastereomer is soluble.

15 Another aspect of the present invention is to increase the yield of the desired diastereomer by allowing the undesired diastereomer to equilibrate in solution to provide additional desired diastereomer that precipitates from solution, and thereby in-
20 crease the yield of the desired diastereomer at the expense of the undesired diastereomer.

 These and other aspects and novel features of the present invention will become apparent from the following detailed description of the preferred
25 embodiments.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

 The present invention is directed to a method of preparing a desired diastereomer of a polycyclic compound having two asymmetric carbon
30 atoms as members of a ring system. The method

utilizes an improved Pictet-Spengler reaction that provides a desired tetrahydro- β -carboline diastereomer in high yield, high purity, and in a short process time. The improved Pictet-Spengler reaction
5 also avoids the use of TFA in the reaction.

Although the synthesis of Compounds (I) and (II) are particularly discussed herein, the present method is not limited to these compounds. The present method also can be used to synthesize
10 the desired diastereomer of other tetrahydro- β -carbolines by a judicious selection of starting tryptophan ester, e.g., the D- or L-form, the starting aldehyde, and the reaction solvents utilized in the present modified Pictet-Spengler cycli-
15 zation reaction.

Typically, the Pictet-Spengler reaction proceeds through generation of an imine under neutral conditions, then effecting cyclization using trifluoroacetic acid (TFA) in dichloromethane
20 (CH_2Cl_2) at a low temperature (4°C). In addition to starting with an imine, N-substitution of the tryptophan amino ($-\text{NH}_2$) group often is used to provide a *cis*-diastereomer. The Pictet-Spengler reaction disclosed in U.S. Patent No. 5,859,006 uses such condi-
25 tions. As discussed above, the standard Pictet-Spengler reaction has the disadvantages of a long cycle time, a low yield of the desired *cis*-diastereomer, and use of the corrosive TFA.

The present invention overcomes problems
30 associated with the classic Pictet-Spengler reaction, e.g., improves the yield and purity of the

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desired diastereomer, and utilizes a more facile synthetic route. In particular, the present invention is directed to a simplified Pictet-Spengler reaction for generating a second ring stereogenic center, wherein the desired *cis*- or *trans*-diastereomer can be prepared in high yield and purity by performing the reaction in a solvent in which the desired diastereomer is insoluble and the undesired diastereomer is soluble. The modified Pictet-Spengler reaction of the present invention also utilizes an N-unsubstituted starting material, e.g., tryptophan, as the hydrochloride salt, and eliminates the use of TFA. The elimination of TFA from the reaction has substantial advantages, including improved isolation/identification of the tryptophan methyl hydrochloride and overcoming the corrosive properties of TFA.

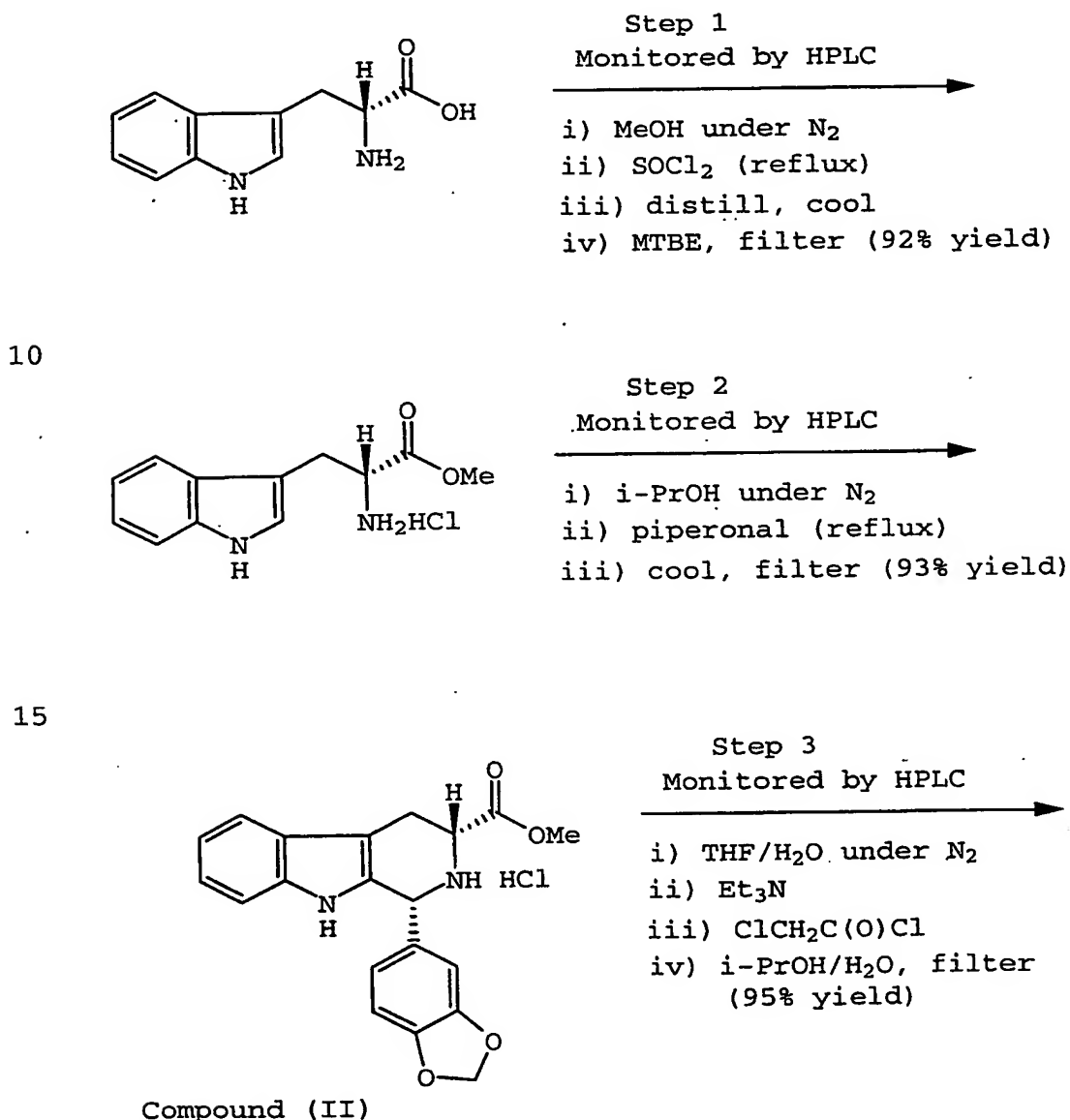
The selection of a proper solvent for use in the present modified Pictet-Spengler reaction is well within the skill of persons in the art. For example, in the preparation of Compound (II) by the Pictet-Spengler cyclization reaction, isopropyl alcohol was found to solubilize the undesired *trans*-diastereomer, whereas the desired *cis*-diastereomer precipitated from the reaction mixture. In addition, the solubilized *trans*-diastereomer is in dynamic equilibrium with the desired *cis*-diastereomer. Accordingly, as the *cis*-diastereomer Compound (II) is formed in solution and immediately precipitates, its concentration is lowered relative to the remaining *trans*-diastereomer Compound (IIa),

thereby providing a concentration differential that forces the equilibrium to provide additional *cis*-diastereomer. This continuous driving of the reaction increases both the yield and purity of the
5 desired *cis*-diastereomer.

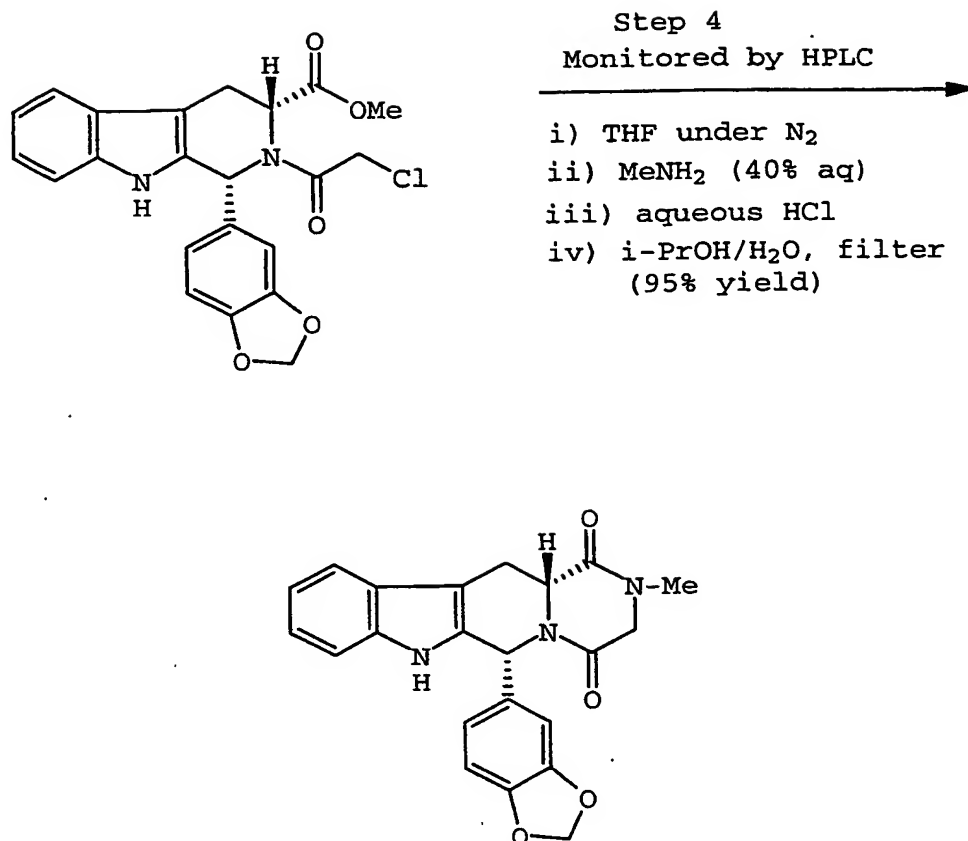
In particular, the present invention utilizes a modified Pictet-Spengler cyclization reaction to form a tetrahydro- β -carboline ring system having two stereogenic centers. The reaction is
10 performed in a solvent wherein the desired diastereomer is soluble at reflux temperature or below, and the undesired diastereomer is insoluble at reflux temperature or below. This solubility difference allows a fast and easy separation of the desired
15 diastereomer from the undesired diastereomer. Furthermore, the dynamic *cis-trans* equilibrium in solution allows a more complete conversion of the starting materials to the desired diastereomer, and a more complete separation of the desired diastere-
20 omer from the undesired diastereomer. Accordingly, another advantage of the present invention is a decrease in costs attributed to a more efficient use of reagents.

As previously stated, the selection of a
25 reaction solvent having the requisite solubility properties is within the ability of a person skilled in the art. The selection merely requires determination of the solubility of each diastereomer in a particular solvent, and a solvent selection that
30 meets the above-described solubility/insolubility parameters for the two diastereomers.

The following is a nonlimiting example of the present invention, illustrating the synthesis of Compound (II) by the modified Pictet-Spengler reaction (Step 2), and the subsequent synthesis of Compound (I) from Compound (II) (Steps 3 and 4).



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5

In general, the synthesis of compound (I) using the method of the present invention involves a four-step synthetic pathway. The first step is an esterification in methanol (MeOH) using thionyl chloride (SOCl₂) under reflux. The product is crystallized and isolated by filtration. The second step involves the present novel and simplified variation of the Pictet-Spengler reaction, wherein D-tryptophan methyl ester hydrochloride is admixed with piperonal in isopropyl alcohol (i-PrOH) and heated under reflux to form a mixture of diaster-

eomeric adducts. Because the desired *cis*-diastereomer (Compound (II)) is substantially insoluble in isopropyl alcohol at reflux temperature and below, the *cis*-diastereomer crystallizes from solution leaving a dynamic *cis*-*trans* equilibrium in solution. As the *cis*-diastereomer precipitates from the isopropyl alcohol, the equilibrium is driven towards the *cis*-diastereomer until the concentration of the *cis*-diastereomer is sufficiently low to remain in solution. The desired diastereomer is isolated in greater than 90% yield by crystallization and filtration.

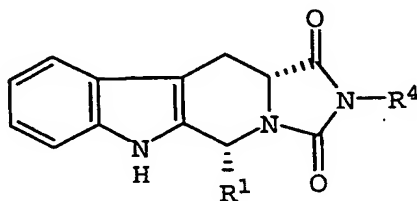
The third step involves an aqueous tetrahydrofuran (THF) acylation of the amino (NH₂) moiety of Compound (II), followed by crystallization and filtration. Ring closure with methylamine (MeNH₂) completes the ring-forming sequence. After solvent exchange, the product is crystallized from aqueous isopropyl alcohol or other suitable solvent, and filtration provides Compound (I) in an overall yield of about 77%.

In general, the present modified Pictet-Spengler reaction can be used to prepare the desired diastereomer of tetrahydro- β -carboline-based compounds without limitation. For example, the present modified Pictet-Spengler reaction can be used to synthesize the desired diastereomer of classes of compounds disclosed in U.S. Patent Nos. 5,859,006; 5,981,527; 6,001,847, WO 02/28859, WO 02/28865, WO 02/10166, WO 02/36593, WO 01/94345, WO 02/00658, WO 02/00657, WO 02/38563, WO 01/94347, WO 02/94345,

WO 02/00656, PCT/US01/49393, PCT/US02/13719,
PCT/US02/00017, PCT/US02/10367, PCT/US02/13703,
PCT/US02/11791, and PCT/US02/13897, each incorpo-
rated herein by reference, and other substituted
5 tetrahydro- β -carbolines.

In addition to the preparation of tetra-
hydro- β -carboline diketo-piperazines, like Compound
(I), the present method can be used to prepare
tetrahydro- β -carboline hydantoins (III) of desired
10 stereochemistry by reacting a compound such as
Compound (II) with an isocyanate having a formula
 R^4NCO , wherein R^4 is aliphatic or aromatic. See U.S.
Patent No. 6,001,847, incorporated herein by refer-
ence.

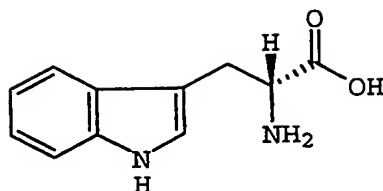
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(III)

The following provides a detailed exem-
20 plary preparation of Compound (I) utilizing the
method of the present invention.

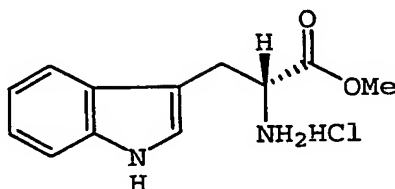
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Step 1

Monitored by HPLC

- i) MeOH under N₂
ii) SOCl₂ (reflux)
iii) distill, cool
iv) MTBE, filter (92% yield)

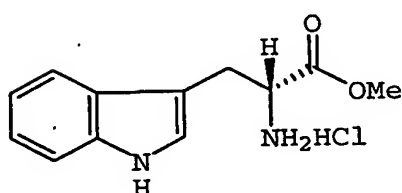
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10 D-Tryptophan (50.0 kg, 245 mol) was suspended in MeOH (270 L), then added to a prepared solution of SOCl₂ (67.0 kg, 563 mol) in MeOH (250 L) at ambient temperature under a nitrogen (N₂) atmosphere. The resulting solution was stirred at
15 reflux for 1 to 2 hours, then MeOH was distilled from the reaction mixture to about 50% of original volume. Methyl t-butyl ether (MTBE) (350 L) was added, and the solution was cooled to 0° to 5°C, with continued stirring for 1 hour. The product was
20 filtered, washed with cold MTBE (150 L), and dried in vacuum at 60°C to yield 57.6 kg (92.4%) of D-tryptophan methyl ester hydrochloride. ¹H NMR (400 MHz DMSO) δ: 11.15 (1H, s), 8.70 (2H, exch.), 7.50 (1H, d, J=8.2 Hz), 7.35 (1H, d, J=8.2 Hz), 7.24 (1H, s), 7.08-7.05 (1H, m), 7.00-6.97 (1H, m), 4.18-4.16
25 (1H, m), 3.61 (3H, s), 3.36-3.25 (2H, m). HPLC

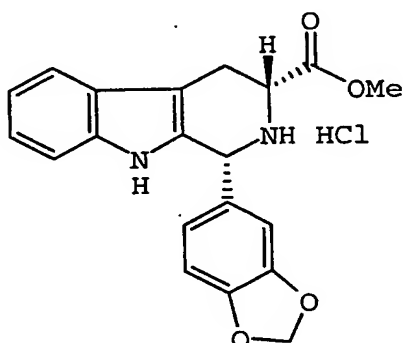
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Details: Column: SB-Phenyl 4.6 x 250 mm; Eluent: Isocratic 80% (H₂O+0.1% TFA)/20% ACN (acetonitrile); Temperature: 40°C; Flow Rate = 1 mL/min; UV Detection = 285 nm; Injection Volume = 20 µL; Diluent = 1:1 ACN/H₂O; and Retention Time = 10.0 min.

Step 2

Monitored by HPLC

- i) i-PrOH under N₂
ii) piperonal (reflux)
iii) cool, filter (93% yield)



(Compound II)

D-Tryptophan methyl ester hydrochloride (50.0 kg, 196 mol) was suspended in isopropyl alcohol (500 L) and treated with piperonal (32.4 kg, 216 mol) at ambient temperature under an N₂ atmosphere. The mixture was stirred between 70°C and reflux (82°C) for 16 to 18 hours. At this time, the reaction mixture contained less than 3% Compound

IIa. The reaction mixture then was cooled to 0°C, filtered, and washed with cold isopropyl alcohol (150 L). The product was dried under vacuum at less than 60°C to yield 69.8 kg (92%) of *cis*-1-(1,3-benzodioxol-5-yl)-2,3,4,9-tetrahydro-1H-pyrido[3,4-b]indole-3-carboxylic acid methyl ester (Compound II)). ¹H NMR (400 MHz DMSO) δ: 10.81 (1H, s), 10.67 (1H, exch.), 10.21 (1H, exch.), 7.52 (1H, d, J=8.0 Hz), 7.27 (1H, d, J=8.0 Hz), 7.11 (1H, m), 7.05-6.95 (4H, m), 6.08 (2H, s), 5.85 (1H, m), 4.71 (1H, m), 3.82 (3H, s), 3.39-3.23 (2H, m). HPLC Details: Column: SB-Phenyl 4.6 x 250 mm; ACN/(H₂O+0.1% TFA) gradient; Temperature: 40°C; Flow Rate = 1 mL/min; UV Det. = 285 nm; Injection Volume = 20 µL; Diluent = 1:1 ACN/H₂O; Sample concentration: about 0.1 mg/mL; and Retention time = 6.0 min.

In a preferred method of preparing Compound (II) by the present method, a small seed amount of Compound (II), i.e., about 0.05% to about 1%, and preferably about 0.05% to about 0.25%, based on the weight of D-tryptophan methyl ester hydrochloride, is added to the reaction mixture prior to heating. This seed amount induces crystallization of the *cis*-carboline Compound (II) in the reaction mixture.

When isopropyl alcohol is used as the solvent, it is preferred that the alcohol is anhydrous, e.g., 0.1% water or less, by weight, because appreciable amounts of water can adversely affect the rate of reaction. It is especially preferred that the isopropyl alcohol is essentially free of

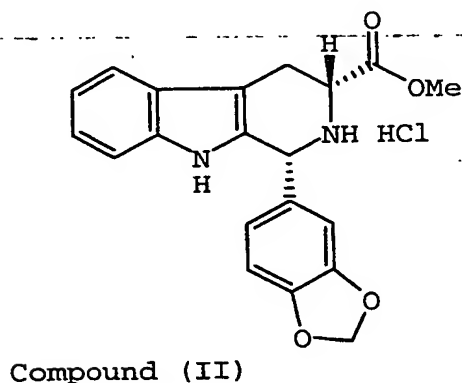
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acetone, i.e., contains 0.3% acetone or less, by weight, to avoid formation of an undesired by-product.

5 Use of a higher boiling solvent (e.g., n-propanol, toluene, dimethylformamide, acetonitrile, or acetic acid) leads to faster reaction times with comparable product yield and purity.

Other solvents useful in the preparation of Compound (II) using a Pictet-Spengler reaction
10 (Step 2) of the present invention include, but are not limited to, aromatic solvents (e.g., toluene, benzene, or xylene), a nitrile (e.g., acetonitrile or propionitrile), an ester (e.g., ethyl acetate), an alcohol (e.g., a propanol or butanol), an ether
15 (e.g., THF, MTBE, or dioxane), an aliphatic hydrocarbon (e.g., hexane, heptane), an organic acid (e.g., acetic acid), mixtures thereof, and aqueous solutions thereof.

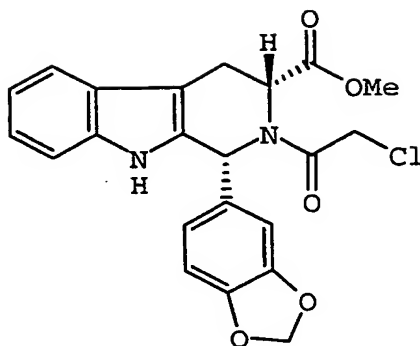
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Step 3

Monitored by HPLC

- i) THF/H₂O under N₂
- ii) Et₃N
- iii) ClCH₂C(O)Cl
- iv) i-PrOH/H₂O, filter (95% yield)

25



The substituted tetrahydro- β -carboline
5 hydrochloride (II) (83.7 kg, 216 mol) was suspended
in THF (335 L) and deionized water (84 L), and
treated with triethylamine (Et_3N) (57.0 kg, 560 mol)
at 0°C to 20°C under an N_2 atmosphere. Chloroacetyl
chloride ($\text{ClCH}_2\text{C}(\text{O})\text{Cl}$) (34.2 kg, 300 mol) in dry THF
10 (0.6 volumes) then was added at a rate to maintain
the temperature at 0°C to 10°C, followed by stirring
the reaction mixture for two hours. The reaction
was monitored by HPLC for a Compound (II) content of
4%, by weight, or less. After the acylation reac-
15 tion was completed, the reaction mixture was sub-
jected to distillation, under vacuum at 30°C to
50°C, to reduce the volume by about 30%. Then,
water (84 L) and isopropyl alcohol (335 L) were
added, and the reaction mixture was distilled a
20 second time under reduced pressure at 30°C to 50°C
to remove about 20% of the volume. The reaction
mixture then was cooled to 20°C to 25°C and stirred
for two hours. The reaction product crystallized,
and was filtered and washed with isopropyl alcohol.
25 The reaction product was dried under vacuum at 80°C
to yield 86.7 kg (95%) of chloroacetyl carboline

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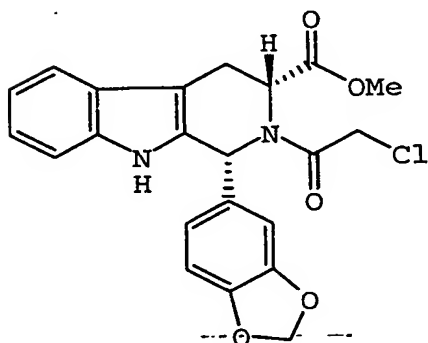
cis-1-(1,3-benzodioxol-5-yl)-2,3,4,9-tetrahydro-1H-pyrido[3,4-b]indole-3-carboxylic acid methyl ester.

¹H NMR (400 MHz DMSO) δ : 10.86 (1H, s), 7.54 (1H, d, J=7.4), 7.27 (1H, d, J=8.0), 7.11-6.99 (2H, m),
5 6.81-6.75 (2H, m), 6.63 (1H, s), 6.45 (1H, d, J=8.2), 5.97 (2H, d, J=5.8), 5.19 (1H, d, J=6.6),
4.83 (1H, d, J=14), 4.43 (1H, d, J=14), 3.45 (1H, d, J=16), 3.10-3.03 (4H, m).

Alternative solvents for Step 3 include
10 low molecular weight alcohols, such as isopropyl alcohol or n-propyl alcohol; acetone; and methylene chloride.

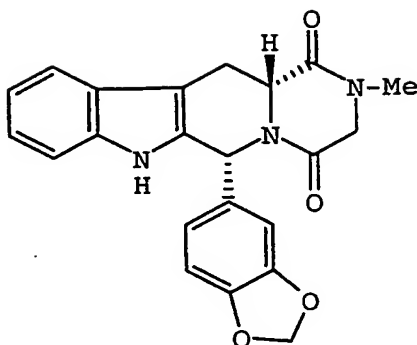
Step 4

15



Monitored by HPLC

- i) THF under N₂
ii) MeNH₂ (40% aq)
iii) aqueous HCl
iv) i-PrOH/H₂O, filter
(95% yield)



Compound (I)

5 The chloroacetyl carboline (86.0 kg, 201 mol) was added to THF (430 L), and the resulting mixture was heated to 30°C to 55°C under an N₂ atmosphere and stirred. The resulting solution then
10 was filtered at a temperature of 45°C to 50°C to remove undissolved particles. Methylamine (78.2 kg, 1000 mol) then was added to the solution at a temperature of 5°C to 25°C. The resulting mixture was stirred at a temperature of 30°C to 55°C for
15 about 1 hour, or until HPLC analysis indicated a complete reaction, i.e., less than 1% of the chloroacetyl carboline remained. The mixture was cooled to 0°C to 30°C, isopropyl alcohol (344 L) and water (175 L) then were added, followed by 12M
20 hydrochloric acid (67 L) to neutralize the excess methylamine, i.e., to pH 2 to 9.4. Upon essentially complete removal of THF by distillation, the solution was treated with isopropyl alcohol (260 L) and water (75 L) and cooled to -5°C to 30°C, followed by
25 stirring for two hours to crystallize the product. The product was filtered and washed with cold (0°C

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to 5°C) 50% aqueous isopropyl alcohol. The wash solvent was filtered at -5°C to 30°C, and the product was dried under vacuum at 80°C or less (e.g., 70°C to 80°C) to yield 75 kg (94.6%) of Compound (I). For increased purity, Compound (I) optionally can be recrystallized from acetic acid.

A reference standard was prepared in the same manner, with additional purification by double recrystallization from glacial acetic acid (HOAc).

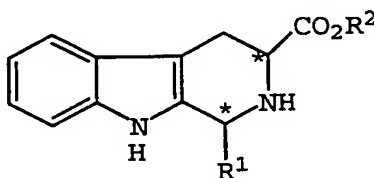
Compound (I) was dissolved in 13 volumes of HOAc at 80°C, and the solution was concentrated to one-third original volume and then cooled to ambient temperature. The product was filtered, washed with MTBE, and dried in vacuum at 80°C. ¹H NMR (400 MHz, DMSO) δ: 11.0 (1H, s), 7.52 (1H, d, J=7.3 Hz), 7.28 (1H, d, 7.9 Hz), 7.28 (1H, d, J=7.9 Hz), 7.06-6.98 (2H, m), 6.85 (1H, s), 6.76 (2H, s), 6.11 (1H, s), 5.91 (2H, s), 4.40-4.35 (1H, dd, J=4.27, 11.6 Hz), 4.17 (1H, d, J=17.1 Hz), 3.93 (1H, d; J=17.1), 3.54-3.47 (1H, dd, J=4.6, 11.3 Hz), 3.32 (1H, s), 3.00-2.91 (4H, m). HPLC Details: Column: Zorbax SB-Phenyl, 4.6 mm i.d. x 25 mm; 2.5 μm particles; Mobile Phase: acetonitrile, 0.1% TFA in water; Flow rate = 1.0 mL/min.; Detector wavelength = 285 nm; Injection volume = 20 μL; Column temperature = ambient; and Retention time = 9.0 min.

Obviously, many modifications and variations of the invention as set forth above can be made without departing from the spirit and scope thereof, and, therefore, only such limitations

should be imposed as are indicated by the appended claims.

WHAT IS CLAIMED IS:

1. A method of preparing a desired diastereomer of a tetrahydro- β -carboline having a formula



comprising the steps of:

- (a) providing a tryptophan esterified using an alcohol having a formula R²OH; and
- (b) reacting the tryptophan ester of step (a) with an aldehyde having a formula R¹CHO to provide the desired diastereomer and an undesired diastereomer, wherein the reaction is performed in a solvent in which the desired diastereomer is insoluble and the undesired diastereomer is soluble.

2. The method of claim 1 wherein the desired diastereomer is insoluble in the solvent of step (b) at reflux temperature or lower, and the undesired diastereomer is soluble in the solvent of step (b) at reflux temperature or lower.

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3. The method of claim 1 wherein the alcohol R^2OH is selected from the group consisting of methanol, ethanol, isopropyl alcohol, n-propyl alcohol, n-butyl alcohol, sec-butyl alcohol, t-butyl alcohol, and mixtures thereof.

4. The method of claim 1 wherein the alcohol R^2OH comprises methanol.

5. The method of claim 1 wherein the aldehyde is an aliphatic aldehyde.

6. The method of claim 1 wherein the aldehyde is an aryl aldehyde.

7. The method of claim 1 wherein the aldehyde R^1CHO is piperonal.

8. The method of claim 1 wherein the desired diastereomer is the *cis*-diastereomer.

9. The method of claim 1 wherein the tryptophan is D-tryptophan.

10. The method of claim 1 wherein the desired diastereomer is *trans*-diastereomer.

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11. The method of claim 1 wherein the solvent in step (b) is selected from the group consisting of an alcohol, an aromatic solvent, a nitrile, an ester, an ether, an aliphatic hydrocarbon, an organic acid, mixtures thereof, and aqueous solutions thereof.

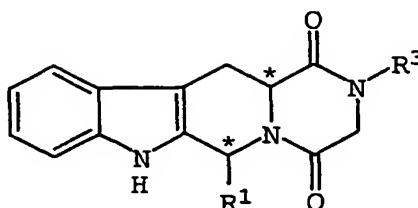
12. The method of claim 1 wherein the solvent in step (b) is selected from the group consisting of isopropyl alcohol, n-propanol, n-butanol, toluene, xylene, benzene, acetonitrile, propionitrile, acetic acid, ethyl acetate, tetrahydrofuran, methyl t-butyl ether, dioxane, mixtures thereof, and aqueous solutions thereof.

13. The method of claim 1 wherein the desired diastereomer is the *cis*-diastereomer, and the solvent of step (b) is an alcohol.

14. The method of claim 13 wherein the alcohol is selected from the group consisting of isopropyl alcohol, n-propyl alcohol, n-butanol, and sec-butyl alcohol.

15. The method of claim 13 wherein the alcohol is isopropyl alcohol.

16. A method of preparing a compound having a formula



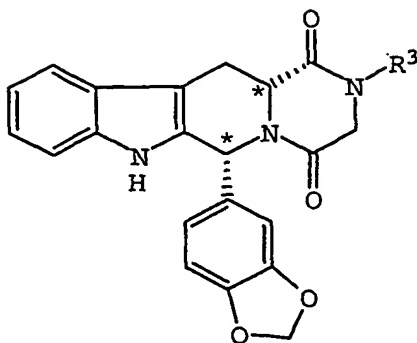
comprising the steps of:

- (a) providing a desired diastereomer of a tetrahydro-β-carboline by the method of claim 1;
- (b) reacting the tetrahydro-β-carboline with chloroacetyl chloride to provide an N-substituted tetrahydro-β-carboline; and
- (c) reacting the N-substituted tetrahydro-β-carboline with an amine having a structure R³NH₂, wherein R³ is C₁₋₆alkyl or hydro.

17. The method of claim 16 wherein the amine is selected from the group consisting of ammonia, methylamine, ethylamine, propylamine, isopropylamine, butyl amine, and sec-butyl amine.

18. The method of claim 15 wherein the amine is methylamine.

19. The method of claim 16 wherein the compound has a structure

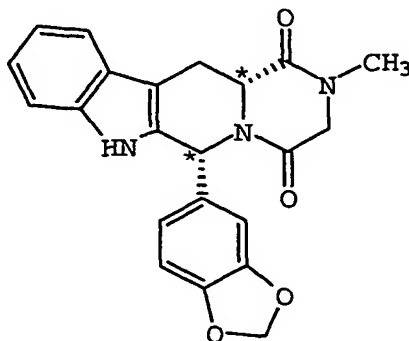


20. The method of claim 19 wherein R³ is methyl.

21. The method of claim 19 wherein the compound is purified by recrystallization from glacial acetic acid.

22. The method of claim 23 wherein step (c) is performed in tetrahydrofuran, and wherein the tetrahydrofuran is removed and replaced with an alcohol for isolation and purification of the compound.

23. A method of preparing a compound having a structural formula:



comprising the steps of:

- (a) esterifying D-tryptophan in methanol and thionyl chloride to provide D-tryptophan methyl ester hydrochloride;
- (b) reacting the D-tryptophan methyl ester hydrochloride with piperonal in refluxing isopropyl alcohol to provide *cis*-1-(1,3-benzodioxol-5-yl)-2,3,4,9-tetrahydro-1H-pyrido[3,4-b]indole-3-carboxylic acid methyl ester;
- (c) reacting the product of step (b) with chloroacetyl chloride and triethylamine to provide *cis*-1-(1,3-benzodioxo-5-yl)-2,3,4,9-tetrahydro-1H-pyrido[3,4-b]indole-3-carboxylic acid methyl ester; and
- (d) reacting the product of step (c) with methylamine to provide the compound.

INTERNATIONAL SEARCH REPORT

Interr Application No
PCT/US 03/22039

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 C07D471/14 C07D471/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 C07D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the International search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, BEILSTEIN Data, CHEM ABS Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	BAILEY, P. D. ET AL.: "Diastereo- and enantioselectivity in the Pictet-Spengler reaction" J. CHEM. SOC. PERKIN TRANS. 1, 1993, pages 431-439, XP009018958 Page 432, table 1; page 436.	1-15
X	MADRIGAL, A. ET AL.: "The fate of the tryptophan stereocenter ..." TETRAHEDRON ASYMMETRY, vol. 11, 2000, pages 3516-3526, XP002259164 Pages 3520-3521, paragraph 3.1; and page 3517, 2nd paragraph.	1-15

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

24 October 2003

Date of mailing of the international search report

10/11/2003

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INTERNATIONAL SEARCH REPORT

Inter Application No
PCT/US 03/22039

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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